

**Affordable NDM (Non-Distribution Media) Vacuum Assisted Resin
Transfer Molding (VARTM) Processing for Large Naval Structures**

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PHASE I FINAL REPORT

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Final Report

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1.0. Identification and Significance of the Opportunity

The primary limitation for the wider use of composites is the cost. (Other aspects such as fire resistance and enhanced properties such as higher service temperatures can also be of concern.) The major cost element of composites is the actual fabrication step which accounts for over 60% of the cost. This is followed by the cost of material waste and then the actual cost of materials used in the part. Therefore, the focus of this SBIR Topic N99-097 is directed to finding and developing new manufacturing concepts which eliminate the under the bag distribution media, material waste, and reduce actual manufacturing costs.

1.1. Background and Identification of the Opportunity

The manufacturing area for composites which is receiving the significant focus for the fabrication for large size structures is VARTM (vacuum assisted resin transfer molding). This is because VARTM represents a fast way of impregnating a fibrous fabric reinforcement in final part form, eliminates the use of the expensive autoclave (process time, labor, capital cost, and part size restraints), and expensive and difficult to store prepregs. There are several varieties of VARTM processes being used including the most publicized process, SCRIMP. Sunrez has recently completed two different process demonstration projects for the NAVY (Carderock) in their Advanced Composite Hull Fabrication Process Evaluation Program. The Sunrez UV-VARTM processes which utilized light curing resins was substantially lower cost with respect to total manufacturing cost than any other VARTM process evaluated or being used commercially.

The advantages of both the light cured UV-VARTM and UV-Prepreg processes include less material waste, faster processing time, far less in-mold time, minimal or no styrene emissions, longer working time, substantially less clean up, and a more robust process than any other process evaluated. These light cured resin processes are well suited for fiberglass with vinyl ester resins, polyester resins and other photocurable resins. In addition, these processes are fast curing and yet permit very long working times for filling the one-part light curable resin into the fibrous reinforcement. These low cost processes, the Sunrez UV-VARTM Process and the Sunrez UV-Prepreg process, do not work with reinforcements and structures opaque to UVA light which is necessary for curing these resins. In addition, many

high performance two part resin systems may cure too fast to be satisfactorily used in VARTM processes for large structures, and the waste and extra labor required for the resin distribution channels is costly.

Based on our lessons learned from these programs, Sunrez has conceived of and plans to develop a new low cost robust VARTM process (the LS VARTM Process) which can impregnate any large scale fabric or fibrous reinforcements very quickly and completely to 60-70% by fiber weight within a few minutes. This process eliminates the under the bag distribution media associated with current VARTM processes and at the same time uses very little auxiliary materials and is very general with respect to what part shapes and sizes can be fabricated.

Elimination of the under bag distribution media will reduce both touch labor and costs of materials associated with other VARTM Systems used in many large Naval composite projects today. The elimination of these distribution media reduces the amount of materials which go directly to the trash can after the part is removed from the mold. Additionally, less resin is required to build a part since the flow media can contain a significant amount of resin. In fact, in thinner laminates there can be more resin in the flow media than in the laminate. The elimination of this distribution media will also allow the fabricator to directly see the laminate prior to and during cure. This gives the fabricator the opportunity to address and fix any areas of the laminate which may not have infused properly or may need additional attention. The value of being able to view the laminate and see any resin poor areas or dry spots prior to cure is significant. The amount of labor to repair a part after it is out of the mold can be almost as high as the amount of labor to produce the part originally. Elimination of the distribution media will cut both time and materials from the lamination of large and small parts. This SBIR will concentrate on proving and developing the LS VARTM Process to make it a more robust and reliable system while not using any distribution media under the bag. Since the LS VARTM Process can be checked visually, exploration will be done on assuring an infusion pattern that will insure complete laminate wetout.

This new LS VARTM Process can readily handle fast curing resins, higher viscosity resins, epoxies and other standard one- and two-part resins together with standard high performance reinforcements such as Kevlar and carbon fibers. Since the LS VARTM process can impregnate preforms and fabric reinforcements so rapidly, it can be used to quickly impregnate fast curing high performance two part resins which normally have too short a working life to utilize standard VARTM processes such as SCRIMP or the Sunrez processes already demonstrated on the Navy Advanced Composite Ship Hull Program. The LS VARTM Process can handle very large structures (areas) and eliminates the waste materials and labor associated with resin distribution channels and flow media while at the same time being very fast.

Based on the previous Sunrez experience with VARTM processes for large parts and structures, and our initial exploratory development experience with the LS VARTM Process, we believe that the total manufacturing costs for large scale and small scale composite parts would approach the cost of the materials actually used in the composite with only a small labor cost and virtually no waste or set up materials cost in contrast to what is currently

encountered with other VARTM processes. It is important to remember that VARTM processes use vacuum on the inside of a bag with atmospheric pressure on the outside of a bag to accomplish up to 14.7 psi pressure for compaction of the laminate. In addition, a good vacuum degasses a composite part better than pressure prior to curing. Sunrez believes that the LS VARTM Process is the manufacturing breakthrough that has been needed to make the VARTM manufacturing approach a robust low cost process for all reinforcements and thermoset resins.

In this proposed program, Sunrez seeks to demonstrate the versatility of this process for various shapes and sizes of composites but focusing on the basic NAVY needs as described in N99-097 utilizing a Navy approved vinyl ester resin and glass fiber reinforcements. An initial estimate of the man hours required per pound of composite part produced by the LS VARTM Process is 0.1 man hours per pound on moderate sized structures. (Our work with the Advanced Composite Ship Hull program demonstrated that less than 0.2 man hours per pound composite with light cured resin processes were achievable even with prototype parts.) Even lower labor costs would be expected on repetitive production runs from the same mold. It must be emphasized that the VARTM processes do not use autoclaves, do utilize low cost molds, and are essentially free of chemical vapor release. The LS VARTM Process is the latest and the largest advance in this technology in over 15 years.

1.2. Technical Description of Opportunity.

Sunrez deliberately set out to conceive and develop the LS VARTM Process in order to find the fastest and lowest cost possible VARTM process and to be able to utilize two-part resins and opaque reinforcements. This meant the elimination of resin distribution tubes and the maximizing the flow rate of the resin over the top of the reinforcement stack. These advantages have been demonstrated in this Phase I proposal. The versatility and any limits for this process will be determined in Phase II. The LS VARTM Process has very wide possibilities which we are only beginning to explore. Sunrez has only described this process to a few companies and we have filed for patent protection. We have had some difficulty in explaining this process to others for the first time because it is truly a different approach. Therefore it is recommended that the reader actually make a model of the process as described to more easily understand the process.

The overall technical objective for Phase I is to demonstrate that the LS VARTM Process can eliminate all consumable waste, resin distribution media, tubes and excess resin, while at the same time dramatically reducing touch labor and overall parts cost. In addition, a further technical objective is to demonstrate the versatility of the LS VARTM Process for fabricating large scale parts (hundreds of square feet in size) containing cores, stealth materials, skin thicknesses over one inch, and structures with nonuniform cross-section. In meeting these overall objectives, the LS VARTM Process should be the prime candidate VARTM process which is needed to achieve low cost composite manufacturing of large Navy structures. The lower composite manufacturing costs with the LS VARTM process will also have a significant impact on manufacturing in the industrial/commercial market including infrastructure, automotive, transportation and marine applications.

2. Tasks

2.1. Develop a family of interchangeable sheets and channel forms for the LS VARTM Process and evaluate vacuum bagging films for suitability with the process which are able to provide the temporary infusion pathways to fabricate 99% of all infusion parts.

The most efficient bagging material will be determined for use with the LS VARTM Process. This material must be flexible enough for the forming of the channels and elastic enough to return to its flat state when the upper vacuum is removed.

Results:

Samples were acquired of likely bagging materials from the film manufactures and evaluated for their elongation properties and elastic return. The evaluation was done by fabricating small test pieces which include flat panels, curves, and corners. A Sunrez vinyl ester resin 4194 was used in the manufacture of these test parts. The following are the results of those trials.

The following films have been tested for elongation

FILM

EVALUATION

Film Technology

PA 6000	Textured Film	Fair elongation Fair return
PA6600C	Textured Film	Fair elongation Fair return
PO 9200	Smooth Film	Good elongation bad return
PET 200	Textured Film	Too Stiff for Maximum flow but may be applicable for thin parts

Airtech Films

Strechlon Series Smooth Films

200	All of these films had adequate elongation but
700	suffered from styrene attack
800	We have requested other prototype films not
900	susceptible to styrene.

Airtech Standard bagging films

KM1300	Good elongation and good return in thicker films
WN 1500	Good elongation, Ok return
DP 1000	Good elongation Ok return

Richmond	
A-5000	Good elongation good return
E-3760	Good elongation good return
Silicone bag	
In house	Excellent elongation excellent return
Reinforced silicone	" " " "

The Airtech KM1300 and the Richmond A-5000 were selected to be used in subsequent trials due to their good elongation and return to the surface of the part after infusion for Task 3. Criteria for selection included: flexibility, ability to reuse, toughness, and clarity.

A number of different contoured sheet patterns were evaluated for the profile which produces the temporary distribution channels for the resin when vacuum is applied to the bagged system. Different materials with different contouring and varying degrees of stiffness were evaluated. Criteria was ease of use of the contoured sheet, cost of the sheet and reusability. After extensive investigation and testing we found that the simplest and easiest sheet pattern was one that could be made from wood strips and similarly shaped urethane strips. These strips allowed us to both control the height and separation between channels. This wood strip system works very well for the initial prototype. And can be molded in composite or cast as a urethane blanket for production.

We have also discovered that many different types of commercially available deep grooved industrial floor mats work very well. These mats work very well for going around corners and slight compound curved areas.

2.2. Identify the Demonstration Parts to be Fabricated and Resins to be Used for Demonstrating the Capabilities of the LS VARTM Process for High Technology Navy Platforms.

During the beginning portion of the project we were fortunate enough to have a concurrent project that provided the access to some aerospace parts for testing. Sunrez opted to use these very expensive and exotic carbon fiber materials. There were 3 different parts to be built which we felt would demonstrate very well the capabilities of the LS Process for the SBIR. These parts were as follows:

3 each - 32 square foot full thickness section of a wing panel. 130 lb carbon fiber Kevlar stitched fabric.

1 each - cored section full size of leading edge advanced shuttle wing.

1 each - cored section scale size of shuttle wing. These parts were to be built with carbon fiber and epoxy and vinyl ester resin.

2.3. Fabricate Each Selected Demonstration Part With the LS VARTM Process With Optimization Where Possible.

Figures 1-6 show wing section part.

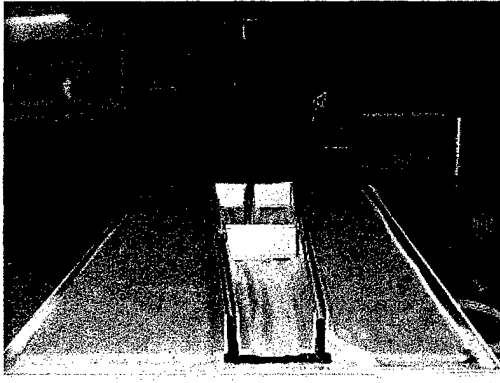


Figure 1 Layup of wing section.
Aluminum angles maintain verticals

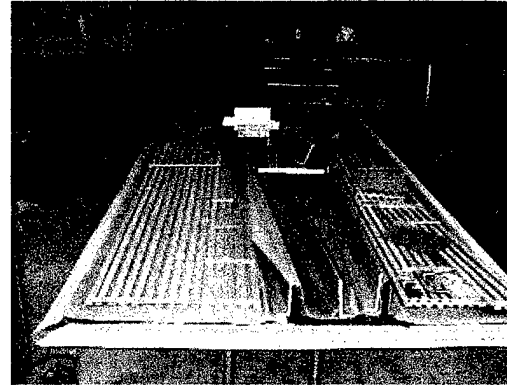


Figure 2 Installation of LS Strips



Figure 3 Blanket for bag protection ready
for bottom bag

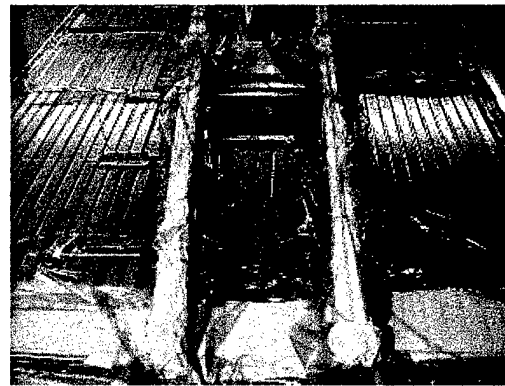


Figure 4 Completed Bagging with LS
Strips and top bag

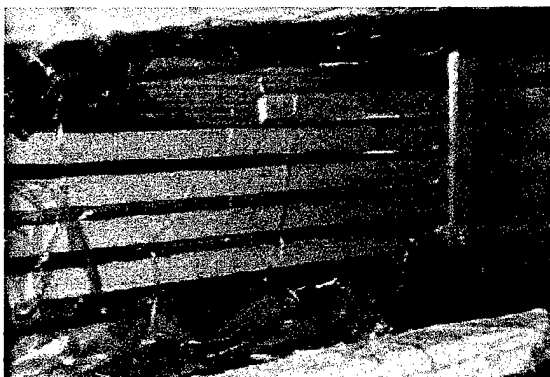


Figure 5 Flow of resin through formed LS
Process channels



Figure 6 Wing section in oven during
infusion.

This part is .5 inches thick with both tapered and straight standing ribs. All of the epoxy resins that were used on the wing sections were high viscosity resins and had a working time of no more than 1 hour after warming to 150 degrees F. The parts were heated to 130 degrees F throughout. The infusion was accomplished on the 32 square foot parts in 25 to 50 minutes depending on the infusion flow pattern. All areas of the laminate were wet out. The part was then left under vacuum and allowed to cure at 250 deg F. Each was infused in a slightly different manner as far as resin introduction was concerned (resin was started from blades on the first one, from the interior between the blades on the second, and on the outer flats on the third). We found that we had a faster and better overall wetout when the blades were wetout first then the remainder of the part wetout. We also found that we needed to make allowances in the channel forming pattern when crossing folds in the lower bag. The folds under the grid meant that three layers of film had to be lifted from the laminate face in order to pass resin. These areas under the folds did not stop resin flow but dramatically reduced the flow times along the grid. Corrective action was to enlarge grid at areas where bottom bag was folded.

This process was repeated 2 additional times using 3 different epoxy resins of different viscosities. All of the infusion was done at a temperature of 120-150 degrees F. Based on the use of clear films, we could watch the progress of the infusion and control the process by opening and closing both the resin input lines (5-7) and upper vacuum chamber.

This section was meant to demonstrate a full thickness wing section with ribs attached. The materials were sewn together using Kevlar thread to form a rigid preform. The stitching was so tight on these preforms that almost no measurable compaction took place on these parts during full vacuum.

Resulting laminates exhibited fiber content of 50% by volume.

Figures 7-12 show a leading edge section. This part was a balsa cored part with a single layer of carbon fiber fabric on each side of the balsa core on the curved surface and ribs. Since this was a "show" part, vinylester resin was used for room temperature infusion. The catalyst level added to the resin gave a gel time of about one hour. This part was infused from both sides at once. Infusion time was 30 minutes. The resin was allowed to cure overnight at room temperature.

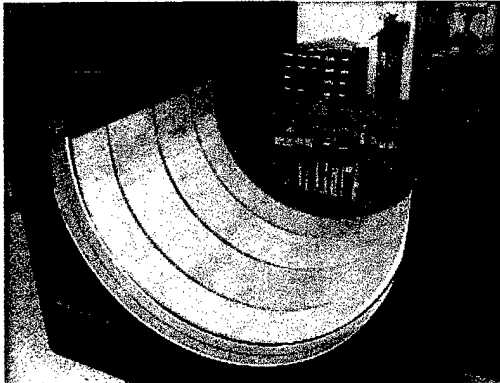


Figure 7 Leading edge with first carbon and Balsa

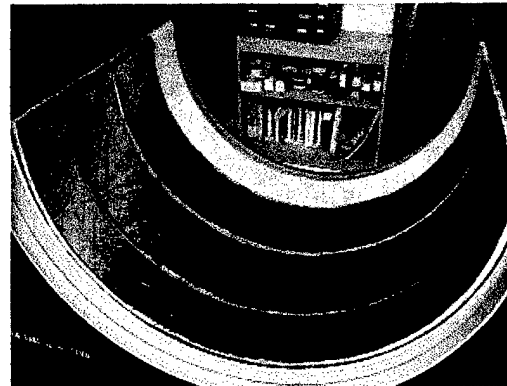


Figure 8 Last carbon over balsa core

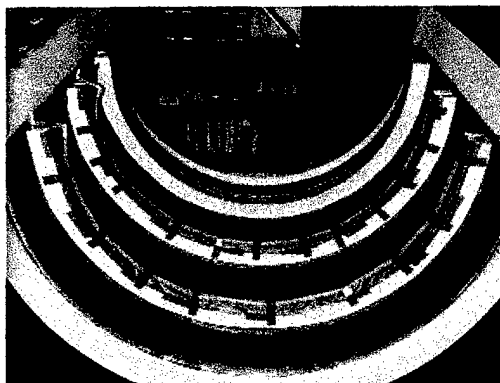


Figure 9 Ribs and LS process materials

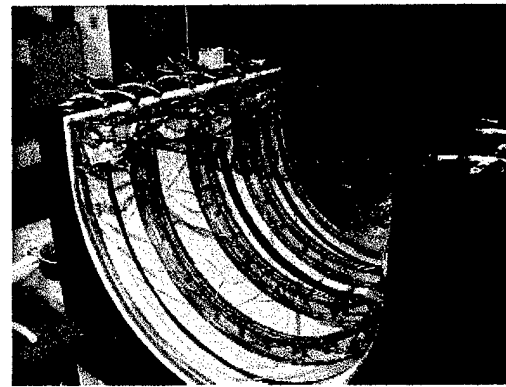


Figure 10 Part during infusion

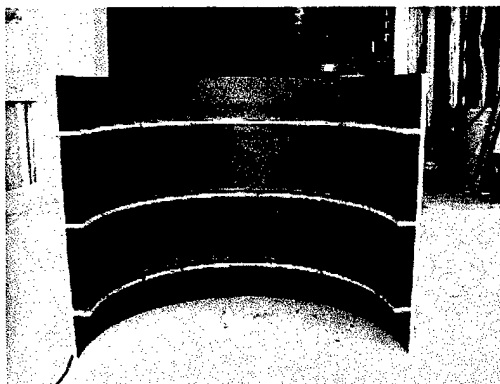


Figure 11 Completed part with ribs



Figure 12 Completed part side view

Figures 13-18 show a scale size wing section with 2 vertical ribs..

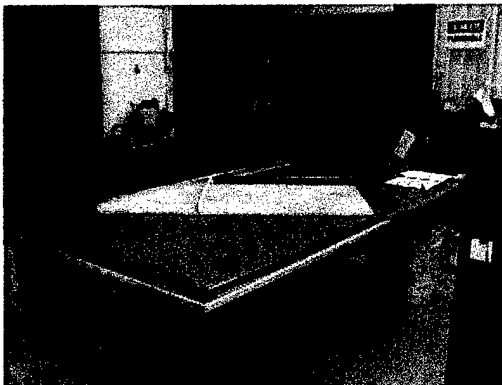


Figure 13 Layout of Scale wing section

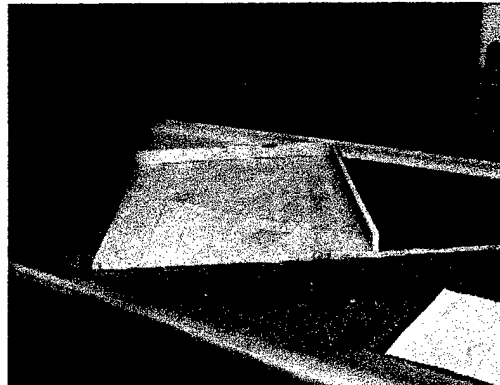


Figure 14 Layout of ribs and Balsa core

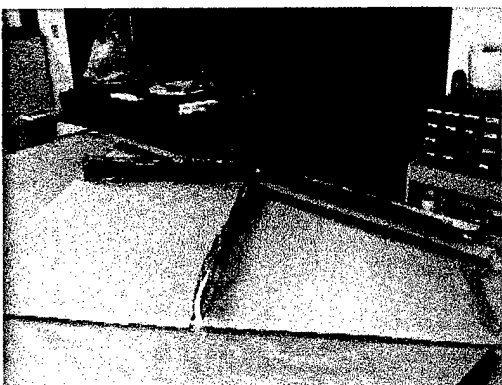


Figure 15 Carbon fiber and release cloth



Figure 16 Wing section under Vacuum during infusion

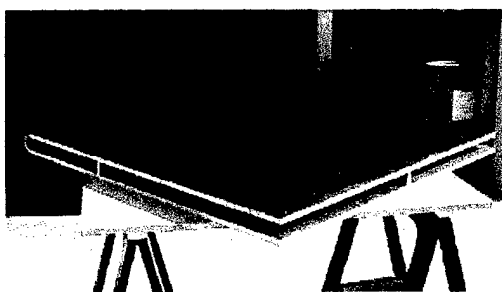


Figure 17 Wing section from ends. Note two internal ribs.

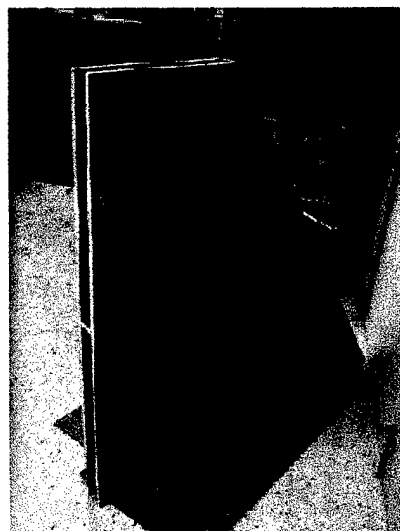


Figure 18 Wing section on edge

Vinyl ester resin was also used on this part. The catalyst level added to the resin gave a gel time of about one hour. Infusion time was about 25 minutes. The resin was allowed to cure overnight at room temperature. The part was molded over a interior mold and floated off the mold using a new process developed by Sunrez. This new process allowed for full vacuum against the part during infusion and floated off the mold by a few thousandths during cure. This allowed for a zero draft mold and additional compression on the part. Normally a vinyl ester shrinks enough in a laminate of this type to lock the part to the mold. Infusion was also accomplished with a vinyl ester resin. The catalyst level added to the resin gave a gel time of about one hour. Infusion time was about 25 minutes. The resin was allowed to cure overnight at room temperature.

On all of the parts, except the leading edge, the infusion was done in a progressive zone pattern. Due to the value of the materials of the full scale wing section (\$20,000+ per laminate) we decided that we would do zone filling to assure that the zone was properly wet out prior to opening the next zone. Filling times within the zones were very fast, which allowed us to infuse the total part in less than the 1 hour open time of the resin.

Infusion on the scale wing section was accomplished by infusing the inside laminate first to assure wet out, then infusing the outer laminate. Since this was a blind infusion we decided that we would witness the resin flowing to the outer edges of the inside laminate prior to infusing the outer skin.

2.6. Determine What Improvements are Needed In Phase II With the LS VARTM Process with Respect to Two Part Resin Systems, Complimentary Processes, Reinforcements, and Part Configuration and Submit Phase I Final Report.

Based on the Phase I Program results, Sunrez will continue to develop new grid/infusion patterns and investigate more bagging materials. We have discovered some areas which need improvement in very specialized one off parts. When standard flat bagging films will be used which will have folds on shaped or compound curved parts, we can plan the grid system for folds in the top laminate bag. On a production part using a dedicated top vacuum bag these folds would not occur and the only allowances necessary are those involving reins flow speeds and zone control if required.

Our results have shown us that a wide channel is more effective than a thin deep channel at the infusion point. And that a narrower taller channel is more effective at the vacuum point (the end of the resin run).

3.0 Recommendations.

Sunrez has demonstrated that the LS-Process preforms as well as any other system available today.

The LS-Process has advantages which no other system has been able to match.

1. NO Under Bag Media.
2. Much lower cost both in operation and in licensing fees (3% of materials only).
3. Minimal waste, if any at all.
4. Completely controllable by the fabricator
5. Easy Recovery if problems arise
6. Absolute control over zone filling, infusion speed, and resin content (up to 73% by glass weight).
7. Can be infused using pressure.
8. New tricks and additional procedures are transferred to fabricators.

The LS- Process should be seriously considered by the Navy as a viable alternative the more expensive and cumbersome SCRIMP process in building large structures. Savings to the Navy's budget for building composite structures could be higher than 10% for the overall composite portion of a project.

Sunrez is very interested in building larger Naval Structural parts utilizing the LS-Process.

Mark Livesay
President

Sunrez Corporation

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13. ABSTRACT (Maximum 200 words) Sunrez Corporation has refined the LS-Process, an improved VARTM (Vacuum Assisted Resin Transfer Molding) process for the fabrication of large scale composite parts and ships. Sunrez has conceived and demonstrated the LS-Process which eliminates all of the under bag flow media usually associated with current VARTM processes. The currently used VARTM processes require an inordinate amount of "under the bag" resin distribution media and tubes and excess resin, which are thrown away after the part is fabricated creating higher material and labor costs. The LS-Process lowers costs with respect to labor and materials and has no under the bag resin distribution media. Sunrez has developed the LS VARTM Process to meets these requirements and is very low cost. In Phase I of this program, the LS VARTM Process was further developed and demonstration parts made which have shown the viability of this process to meet all of the Navy requirements for this program.				
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